CHAPTER 3 NATIONAL INNOVATION SYSTEMS

3.1. Introduction

The production of goods and services is becoming more and more knowledge-intensive – more science-intensive via the better use of existing stocks of academic knowledge, more technology-intensive via the diffusion of advanced equipment, as well as more skills-intensive in terms of managing the increasingly complex knowledge base related to innovative activities.

Therefore, innovation[1] in the knowledge-based economy, according to OECD (1999), is characterized as what follows.

(1) Innovation is an interactive process involving market and non-market institutions. It consists of the creative use of various forms of knowledge, which can be "codified" (in the form of publications, patents, …etc.) or "tacit" (embedded in the "know-how" and dexterity of individuals, in organizational routines, and the like).

(2) Innovation depends on scientific progress in the emerging industries, particularly in the biotechnology.

(3) Innovation requires more than R&D, which is becoming more knowledge-intensive.

(4) Firms are the main actors but do not act alone in technological innovation. Networking and collaboration among firms are now more important than before.

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[1] The types of innovation are illustrated as follows.

(1) *New for the Firm*

The innovation which is *new for the firm* comprises modifications and improvements of existing products or services as well as products or services which are new in the firm's range, extending it or substituting certain items. Usually it is incremental innovation with small-step technical changes applying widely available knowledge. If the innovation is successful, the competitive position of the firm within the same market will be improved.

(2) *New to the Market*

The innovation which is *new to the market* offers products or services which are, at that time, not available elsewhere on the market. Therefore, the firm does not face competing products or services, being a temporary monopoly in a small and specialized market. The technical progress linked to this type of innovation is very broad. The most radical innovations may even be the basis for new technical trajectories, defining the technical opportunities for further innovations, the development of complementary applications, and the emergence of a group of related markets.

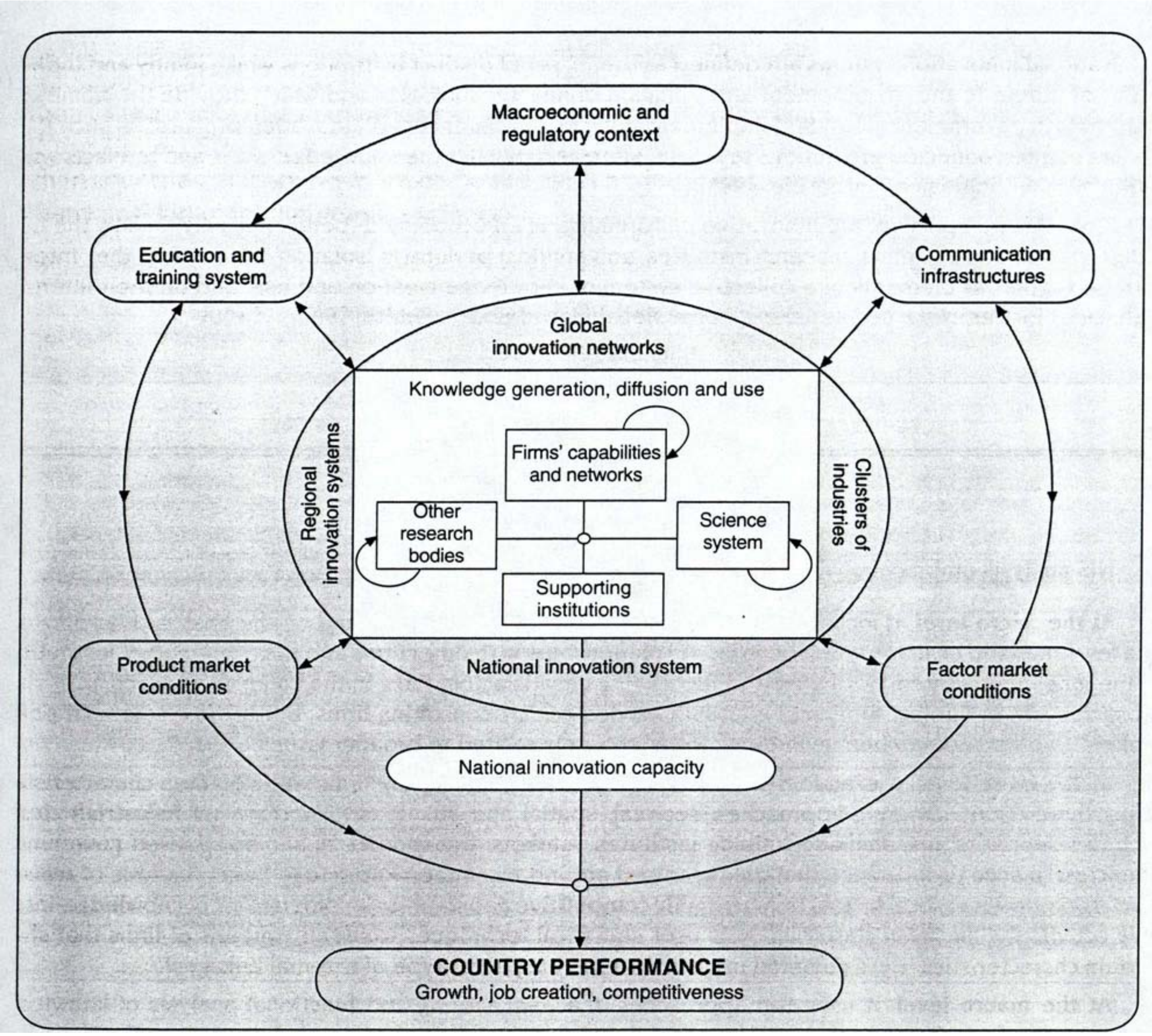
In order to paint a picture of the previous chapter and the above, this chapter summarizes the theoretical underpinnings of the concept of ***National Innovation Systems*** (NIS). It is then used as a conceptual framework to study the biotechnology industry in Taiwan in the following chapters.

3.2. National Innovation Systems (NIS)

Innovation systems can be world-wide, regional or local networks of firms and clusters of industries, which may or may not be confined within a country's borders, but national characteristics and institutional frameworks always play a role in shaping them. This also holds true with regard to the internationalization of innovative activities, which to a large extent reflects foreign investors' perception of the relative strengths of national innovation systems, for example, the infrastructures, the science and technology (S&T) related policies, the academia centers of excellences, or the supply of skilled scientists and engineers… and so on in a country. Therefore, the concept of nation-state is still important even under globalization – both for its institutional mechanisms to integrate domestic resources with public interest, and for its symbolic significance as a community that helps strengthen identity itself.

The market and non-market institutions in a country that influence the generation, direction and speed of innovation constitute a **National Innovation System (NIS)**. It emphasizes interactions and interfaces between various actors (e.g. firms, research institutes, universities) in a country and the workings of the system as a whole rather than the performance of its individual components. NIS is a systemic approach to innovation as a tool for policy analysis. The concept of NIS provides a framework for analyzing the country- (and industry-) specific innovation process in the globalized economy, as well as a guide for S&T policy formation (OECD, 1999) (Figure 3.1).

Figure 3.1: Actors and Linkages in the National Innovation System



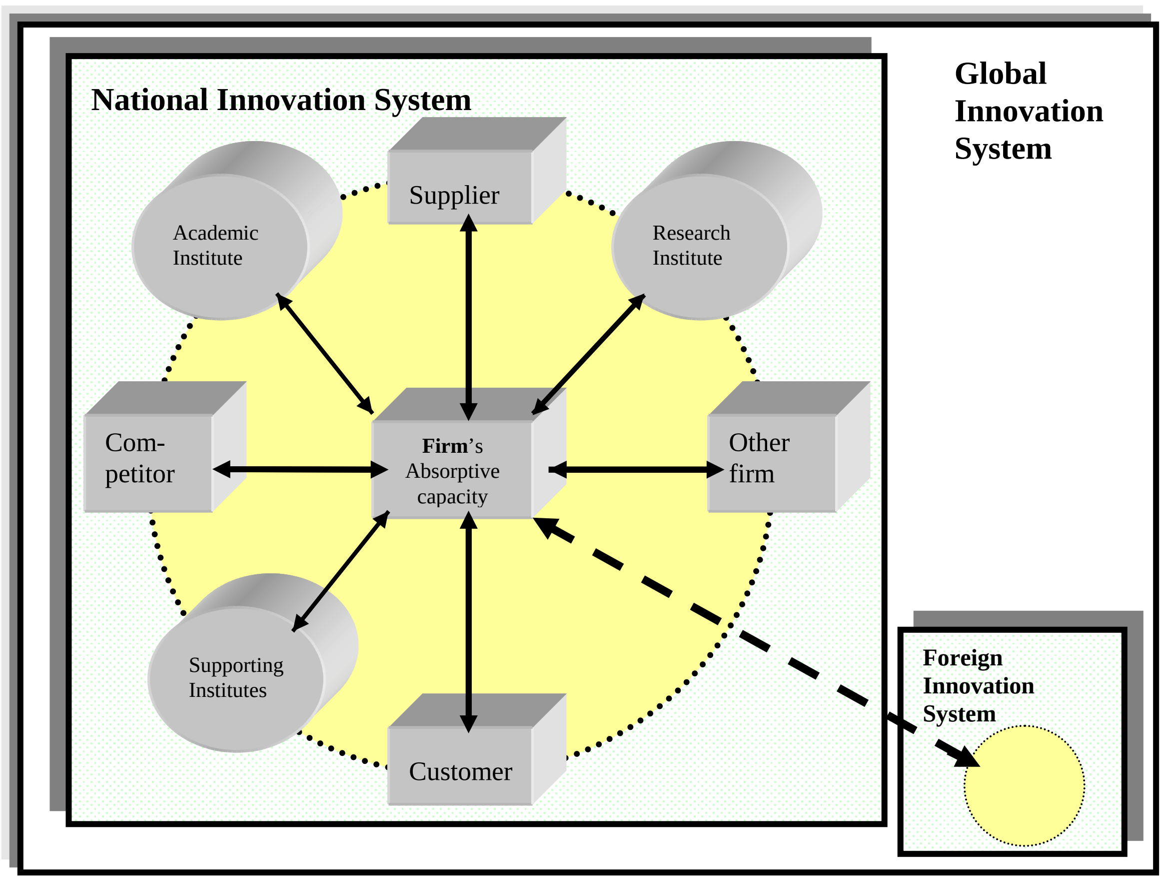
Source: OECD (1999), ***Managing National Innovation Systems***, p.23.

3.3. Definition of NIS

National innovation systems are defined as the "… set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provide the framework within which governments form and implement policies to influence the innovation process. As such it is a system of interconnected institutions to create, store and transfer the knowledge, skills and artifacts which define new technologies. (Metcalfe, 1995)

From this perspective, the innovative performance of an economy depends not only on how the individual institutions (e.g. firms, research institutes, universities) perform in isolation, but on "how they interact with each other as elements of a collective system of knowledge creation and use, and on their interplay with social institutions (such as values, norms, legal framework)". (Smith, 1996) (Figure 3.2)

Figure 3.2: Innovation Systems



Note: ⟷ *Knowledge generation, diffusion and use*

(1) Innovation performance in an economy depends not only on how specific actors (e.g. firms, research institutes, universities) perform, but also on how they interact with one another as elements of an innovation system at local, national and international levels.

(2) There is not a single specific “innovation system” for firms. It is about the exchange between actors belonging to different social systems, say the business sector and academic arena, all of which have influences on firms’ innovativeness.

(3) A firm’s innovation processes are comprised of both internal and external knowledge. A firm depends on external knowledge to enhance its internal innovation efforts, learning from beyond its boundary. External sources of knowledge center on public research, which is supported by government, and carried our by academic and research institutions.

(4) Instead of viewing other firms as competitors, a firm must be able to recognize that some of its opponents are “complementors” who can add value to the firm’s own products and services. Cooperation with complementors turns apparent zero-sum situations into positive-sum games which generate gains to all players. Cooperative as well as competitive strategies are supposed to be exercised through the formation of “innovation system”, where the firm strategically interacts with universities, research institutes, suppliers, customers, competitors, and other industry players to create new knowledge for innovation.

(5) The minor innovations are likely to be influenced by partners from the same industrial sectors, i.e. suppliers or customers, whereas the far-reaching innovations are more likely to be induced by external relations with partners from the different system, say science.

(6) Within an innovation system, universities, research institutes, suppliers, customers, competitors, and other industry players constitute a firm's network, which play a critical role in the innovation process. Numerous feedback loops between the firm and other players in the network characterize all phases of firm's innovation. It is important for a firm to manage such a network for new ideas and information.

(7) In the knowledge-based economy, a firm's competitiveness stems from the specialized knowledge held by the firm, the capacity of absorbing external knowledge, and the ability of the firm to generate new knowledge. "Knowledge creation" has become the source of a given firm's unique and inimitable advantage. New firm-specific knowledge can be developed through the integration of externally sourced knowledge with internal knowledge, as well as through internal research and development.

(8) In terms of clusters, Michael E. Porter (1998) pointed out that economic geography in an era of global competition poses a paradox. In theory, location should no longer be a source of competitive advantage. Open global markets, rapid transportation, and high-speed communications should allow any company to source any thing from any place at any time. But in practice, location remains central to competition. Clusters, or geographic concentrations of interconnected companies, are a striking feature of virtually every national, regional, and even local economy, especially for the knowledge-based industries. Geographic, cultural, and institutional proximity provides companies with special access, closer relationships, better information, stronger motivation, and other tacit advantages that are difficult to tap from a distance. Clusters affect national competitiveness in three broad ways: first, by increasing the productivity of companies based in the cluster; second, by driving the direction and pace of innovation; and third, by stimulating the formation of new businesses within the cluster. Therefore, economic theories of clusters represent a new way of thinking about national economies, and they necessitate new roles for companies, government, and other institutions in enhancing

competitiveness.

Based on the above, NIS-related research topics for R&D collaborations can be summarized as follows.

Table 3.1: NIS Related Research Topics for R&D collaborations

Typology of partners for R&D collaborations ➢ Academia (Universities) ➢ Research Institutions ➢ Competitors or Other Firms (Horizontal Relationships) ➢ Customers or Suppliers (Vertical Relationships)
Motives of R&D collaborations ➢ Access to complementary capabilities ➢ Access to specialized skills ➢ Access to new suppliers and markets ➢ Access to state-of-the-art facilities ➢ Sharing of risk and cost for research ➢ Speeding up innovation process
Organizational modes for R&D collaborations ➢ M&A ➢ Minority equity ➢ Joint venture ➢ Formal agreement ➢ Informal agreement ➢ Consortium ➢ Networking ➢ Licensing ➢ Outsourcing ➢ Sub-contracting
Dimensions of organizational modes for R&D collaborations ➢ Number of partners ➢ Formalization of the agreement ➢ Structure of control ➢ Time horizon ➢ Density of the relationships

3.4. NIS at the firm level

NIS at the micro level focuses on the internal capabilities of the firm and on the links surrounding one or a few firms, and examines their knowledge relationships with other firms and with non-market institutions in the innovation system.

3.4.1. Absorptive Capacity

Cohen and Levinthal (1990) proposed '*Absorptive capacity*' to characterize firm's innovativeness. It is defined as the ability of a firm to recognize new information, assimilate it and apply it to commercial ends. It is a critical component of innovation process relying on external sources of knowledge. Therefore, the internal R&D efforts of firms both allow firms to create new knowledge and enhance their ability to assimilate and exploit external knowledge.

Bayona, Garcia-Marco and Huerta (2001), with a sample of 1,652 Spanish firms, show that firms' motivations for cooperative R&D are related to technological complexity, and to the objective of risk sharing and to the obtaining of financial resources because the innovation process is uncertain and costly. They also found that in order to undertake cooperative R&D, it is necessary to have certain internal capacities in the technological area, which supports for the theory of absorptive capacity.

3.4.2. Firm Size and Research Productivity

Start-up firms and well-established companies have different relative strengths in the pursuit of innovation. Large companies, with their economies of scale, have the synergies among different research projects, while the advantage of newer and smaller firms lies in their greater sensitivity to market conditions. With increasing firm size, research staffs may find themselves out of touch with market conditions and difficult to adapt to the changing environment.

In the United States, many of the new technologies are initially developed by the start-up firms close to the frontiers of science, particularly in the biotechnology industry. Lerner, J. (1993) argued that it may be better to undertake some of research within smaller firms, despite the loss of the scale effects and synergies which may characterize R&D in larger companies, because R&D projects can be evaluated more accurately in small research-based firms. The greater exactitude with which the researchers' performance can be observed and consequently the higher powered incentives which can be offered provide a rationale as to why it may be better to do R&D within smaller units.

Considering the new technological fields, particularly biotechnology, Arrow (1983) suggested that the organizational "distance" between inventors and the people responsible for internal financing of innovation is greater in large firms than in small ones. This generates greater information loss in internal communication (Gambardella, 1995).

From a discovery point of view, as Drews (1995) argued, it will be essential to shorten the time of project turnover as well as to increase the possibility of success for discovery projects and for development compounds. He suggested that these goals can be more easily achieved in small research units than in big ones. It is consistent with Arrow's argument above, that bureaucracy, which always goes along with large organizations, is an impediment to good science, to quick decision making, and to intellectual productiveness in general. Much of the increase in innovative power may be buried under the clumsy structures, layers of hierarchy, incompetence and formality that the well-established firm has created for itself. By contrast, smaller firms can focus on a relatively well-defined specific field, either comprising a few topically related therapeutic areas or specializing in some special but related enabling technologies. A team of scientists matching each other in a small firm is quite enough to generate new ideas, discover new drugs and provide a credible proof of concept within a given area of research. The best biotech firms have shown that small size can be put to the advantage of drug discovery (Drews, 1995).

When radical innovations or new research methods appear (Gambardella, 1995), and when research breakthroughs are so broadly distributed (Powell, 1996), organizational rigidity and inertia hinder the ability of established firms to take advantage of the new opportunities. Newly established firms or small start-ups, with no sunk costs and organizational biases towards the old technologies, should be far more effective than incumbents in exploiting the new fields (Gambardella, 1995). Besides, the small firms, set up by the scientists from universities or research institutes, are usually easier to gain access to new scientific knowledge and state-of-the-art lab equipments in academia, so they can save a lot of the informational cost and physical capital investment in the new fields. Particularly, human capital matters more in the knowledge-based economy. Scientific creativity and highly qualified research staffs, rather than size or scale, have become the critical resources for drug discovery.

3.4.3. Vertical Integration vs. Vertical Disintegration

(1) Transaction Cost

Externalization, either through collaboration or outsourcing, poses high transaction costs. According to Powell (1996), external alliances are hard to set up initially and require considerable skill in sustaining. Such ventures create complicated relations of dependency and obligation, as well as many opportunities for miscommunication and misinterpretation of intentions. These symbiotic arrangements are quite expensive in time and effort. Even fully committed partners may find it difficult to transfer tacit technological know-how across organizational boundaries, especially when the research outcomes are derived primarily from empirical experiences. Furthermore, it is quite difficult to describe it in forms that could be effectively patented or protected by intellectual property right (Gambardella, 1995). Therefore, to reduce transaction costs, a company should prefer to internalize critical stages in drug R&D process and turn to external alliances only when in-house capability is absent (Powell 1996).

However, with the recent advances in molecular biology and genetic engineering, drug innovations have increasingly depended upon knowledge that are “generic” in nature, and thus they can be transferred at low cost among different agents. Besides, with the growth of scientific knowledge and computational capabilities, scale and experience of research are not as important as before, so the knowledge base for drug discovery has become more “divisible”. Therefore, contracts and intellectual property rights can be sorted out more easily than before and the relevant “fragment” of knowledge can be thus exchanged between the firms (Gambardella, 1995). In short, the transaction costs can be reduced under such circumstances, so it encourages the large pharmaceutical companies to resort to external markets or external alliances for drug discovery (Senker and Sharp, 1997)[2].

(2) Complementary Assets

Interfirm collaboration can be advantageous as an R&D strategy because it allows partnering firms to realize economies of “synergies” as a result of pooling resources, production rationalization, risk reduction, and utilization of assets to the efficient scale and scope. Teece proposed the idea of “*complementary assets*”, which two partners possess and these assets are bound up with tacit, firm-specific and often proprietary knowledge. A firm approaches collaboration with specific needs and seeks partners that can match those needs in return for an asset the seeking firm has. Therefore, a firm has a set of competencies it seeks to build on through its relationships with various partners. That is, a firm approaches collaborative agreements in a way that “fills in” the missing pieces of its own competencies. For example, large pharmaceutical companies will utilize biotech partners for any critical skills they have not mastered or to exploit opportunities to which they cannot devote sufficient time or resources (Senker and Sharp, 1997； Powell, 1996).

Particularly, persistent national differences in technological capabilities are a driving force of the globalization of technology. The growth of international

[2] Tapon and Cadsby (1996) also pointed out that low transaction costs occur when the relevant biological and chemical theories are advanced enough that the action of a particular compound on the target molecule can be predicted accurately. Therefore, firms are able to isolate each stage of the R&D process and use market contracts in addition to hierarchical governance.

technology agreements illustrates the firm- and country-specific technological advantages rooted in skills and knowledge. Technological advances could be regarded as products of a global technological system. Therefore, international technological cooperation may be seen to derive from the *complementary* of knowledge and capabilities embedded in firms from different national contexts (Bartholomew, 1997).

Besides, the exchange of the complementary assets involves a learning process (mutual learning). It means that the transfer of tacit and proprietary knowledge for drug R&D usually requires longer-term contracts and tighter interactions. Consequently, it is expected for the partner firms to learn through such alliances (Gambardella, 1995; Senker and Sharp, 1997).

Furthermore, Powell (1996) argued that internal expertise and external collaboration are not substitutes for each other but complementary. Internal capability is indispensable in evaluating research done outside, while external collaboration provides access to information and resources that can not be generated internally. That is collaboration is not just used to compensate for lack of internal capability. Therefore, research alliances are a set of institutional arrangements that are well-suited to the drug discovery process, fraught with considerable uncertainty as well as reliant on high-level scientific expertise and broadly distributed research breakthroughs. As Galambos and Sturchio (1998) showed, most leading pharmaceutical companies have established significant capabilities in the new field by the mid-1990s, but they are continuing to work with specialized biotech firms in order to innovate across a broad range of therapeutic categories.

(3) Risk-Sharing under High Technological Uncertainty

Through collaborative agreements, small research-based firms can shift part of the risk of initial research stages. Small firms might be unable to bear the entire risk of their research efforts, so they need the financial and organizational support of the large companies. Although large established companies would bear some of the risk of starting research under the research alliances, they would nonetheless bear lower risks than with full internalization of these research projects, and they could take advantage of the greater abilities of the small biotech firms in the earlier research stages (Gambardella, 1995).

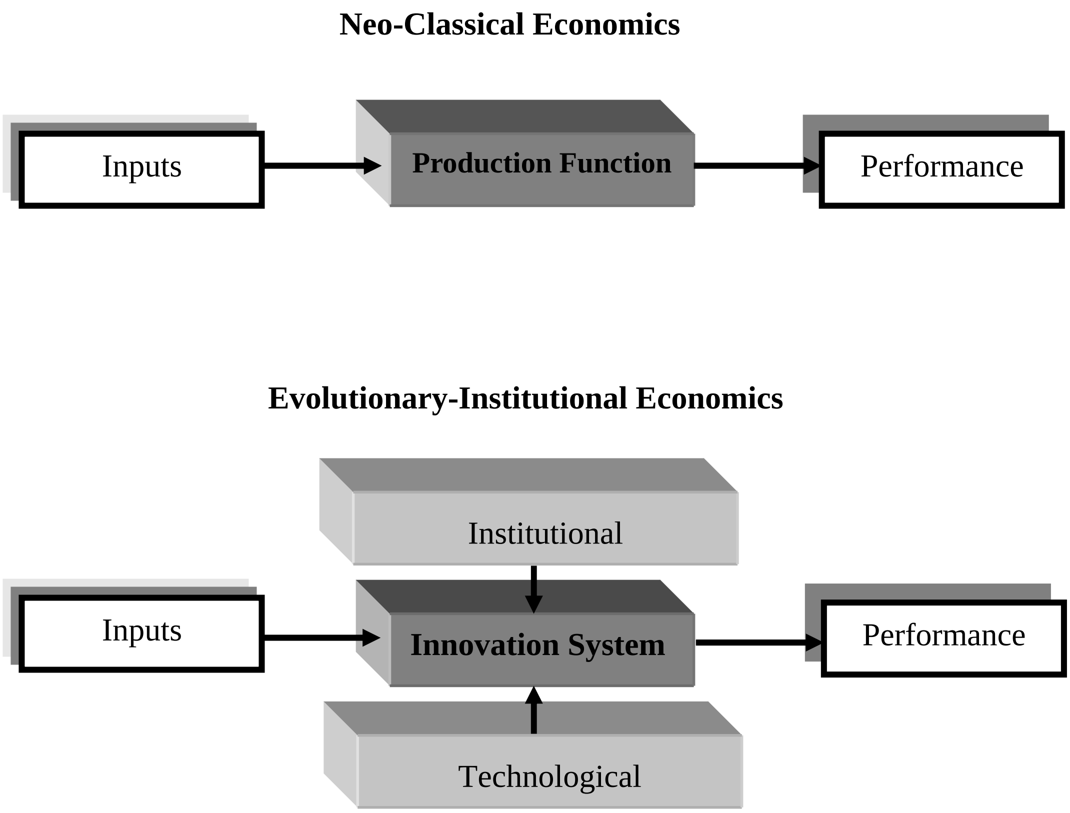
Besides, well-established companies recognize that they can take advantage of knowledge, information, and product opportunities created by small research-based firms. Moreover, they can also take advantage of the fact that, by resorting to an external market for ideas, either they can "buy" the research outcomes that have shown some success, or they can make alliances with the appropriate partners who have promising research or enabling technologies. By doing so, they can save costs of unsuccessful projects, and they can shift part of the risk of initial research stages onto the small research-based firms (Gambardella, 1995).

Furthermore, inter-firm agreements are normally easier to be reversed (or be dissolved) than internal or merger commitments. Given high technological uncertainty of developing some of the bio-pharmaceutical products, maintaining a high degree of freedom (or flexibility) is of importance (Senker and Sharp, 1997).

3.5. Economic Thinking at the Systemic Level

The different streams of economic thinking below provide the theoretical foundations and systemic analysis of technological development and innovation. They could help define the tasks of governments in promoting innovation-led growth under NIS (Figure 3.3).

Figure 3.3: Neo-Classical vs. Evolutionary-Institutional Economics



3.5.1 Neo-Classical Economics

"*Market failure*" has been the main argument in the neo-classical welfare economics for most S&T policies. *Market failure* may arise due to imperfect appropriability conditions or risk, so the private rate of return to R&D is lower than its social return in a competitive market, which implies that the investment of R&D is under the desirable level in an economy (*externality*). It justifies the government intervention to promote technological innovation.

Based on the assumption of production function with constant return to scale (CRS) and exogenous technological progress, ***Neo-Classical Economics*** simplifies the issues of innovation processes by drawing on a representative agent who attempts to reach an optimal equilibrium with perfect rationality[3]. However, theoretical advances and empirical findings in the understanding of innovation processes and their contribution to economic growth have pointed to revisit the rationale of S&T policies. ***New Growth Theory*** (Romer, 1990) challenges some of the main hypotheses underlying the neo-classical view of the contribution of technological change to economic development. It stresses *endogenous growth* by highlighting the increasing returns (IRS) to knowledge accumulation from investment in new technologies and human capital.

Autant-Bernard (2001), with the French case, confirmed the presence of technological externalities stemming from public research activities and highlights their positive impact on innovation. Public research both can contribute to the external stock of public knowledge and can stimulate private effort in innovation. The positive externalities however are limited either in the geographic space or in the scientific space.

Salter and Martin (2001) reviewed the literature on the economic benefits of publicly-funded basic research. They found, from the econometric studies, that there are the spillover and localization effects in research and the economic benefits are very substantial. From the literature based on surveys and on case studies, they identified that the benefits from public investment in basic research can take mainly six forms, which are increasing the stock of useful knowledge, training skilled graduates, creating new scientific instrumentation and methodologies, forming networks and stimulating social interaction, increasing the capacity for scientific and technological problem-solving, and creating new firms.

3.5.2 Evolutionary and Institutional Economics

National innovation systems do vary considerably across countries, and largely exhibit historical and institutional continuity (for biotechnology, see Bartholomew, 1997). Technological development within a national innovation system is considered as an evolutionary and cumulative process, differentiated across firms and locations (Nelson, 1987).

First, ***Evolutionary Economics*** highlights that the innovation process follows "technological trajectories" which show some inertia (*path-dependent*), and involves interactions between different stages of research and development (*non-linear*). That is, technologies accumulate in nations along a "natural trajectory" of development and reflect patterns of past technological advantage. And patterns of technological specialization are distinct across countries and appear to be stable over long periods of time. Therefore, countries are likely to have their greatest scope for future innovation and growth in areas closely related to those in which their firms have been successful in the past. For example, nations with technological advantage in the agricultural, pharmaceutical and chemical industries have accumulated stocks of knowledge that should give them an advantage in biotechnology innovation (Bartholomew, 1997).

Second, national institutional context accounts for such country patterns of innovation (Nelson, 1993). Country-specific technological trajectories are shaped by the systemic and structural components of society, which influence the accumulation and diffusion of knowledge within national innovation systems. For example, innovation patterns and strategies within and between firms, or between firms and universities, reflect the institutional arrangements and societal characteristics. In short, innovation process is shaped by the interplay of market and non-market organizations and by various institutions (such as values, social norms, legal frameworks, and regulations, etc.) (Metcalfe, 1995). Therefore, ***Institutional Economics*** addresses the issues related to the design and coordination of institutions

[3] Please see Chang, H. J. (2000) for the comments on *Neo-Classical Economics*.

and procedures, which involves handling more complex interdependencies, as growth leads to the increasing specialization of tasks and productive tools[4] (North, 1995)[5].

Fritsch and Schwirten (1999) analyzed the data gathered by questionnaires in three Germany regions, and demonstrated that cooperative relationships between publicly-funded research institutions, including universities, and private firms constitute a widespread phenomenon. They found that publicly-funded research institutions are important sources of external knowledge for industrial innovation activities. The contribution of publicly-funded research institutions to private sector innovation is primarily related to the early stages of the R&D process, such as the generation and the development of new ideas. Publicly funded research institutions, through such relationships with private firms, could gain inspiration for guiding their future research activities towards the topics which can be expected to become relevant for private sector.

Some of the universities in the developed countries have internalized the interests of science-based industrial sectors. The actions and strategies of some university researchers often play a central part in the evolution of the knowledge-based economy, with entrepreneurial scientists bridging the gap between the academia and the market[6].

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[4] Please see Chapter 2.

[5] Please see Chang, H. J. and Evans, P. (2000) for the comments on *New Institutional Economics*.

[6] The development of University-Industry relationships is as follows.

Phase I: Universities, academic institutions and research institutions are supposed to provide an educated workforce as well as to create knowledge mainly for academic excellences, not directly for economic benefits.

Phase II: Universities, academic institutions and research institutions, funded by public sector, are supposed to create new ideas to the industry, as well as to carry out strategic research programs for economic development.

Phase III: Universities, academic institutions and research institutions set up a physical place, incubators or science parks, for a closer interaction between their researchers and their industrial clients. They can provide solutions for industrial problems on a contract basis.

Phase IV: Motivated by the interaction with industrial sectors, universities, academic institutions and research institutions initiate research topics for leading technological progress.

The representative biotech firms, such as AMGEN, Biogen, Chiron, Genentech, Immunex, PPL Therapeutics, have spun off from universities or from government-funded research institutes (Table A.1, Appendix 1). Typically, some of their key staff or founders retained formal appointments in research institutes and universities, and have numerous informal networking links that facilitate knowledge flows to the firm. The boundaries that distinguish the firm from the university or from the public research institute had been blurred from all but a legal point of view. The firms, universities and public research institutes form the knowledge base of the biotechnology.

Fransman (2001) explored that the causal relationships between economic, scientific and technological forces let to the cloning of Dolly, the sheep, and that the institutions within which the economic, scientific and technological processes were embedded. He found that economic factors played a crucial role in the birth of Dolly, previously acknowledged as a major scientific breakthrough. The advent of Dolly was not the result, intended or unintended, of purely scientific research but was rather the result of conscious design, i.e. developing transgenic animals for commercial purposes. Expected economic payoffs motivated the research program undertaken at Edinburgh University, the Roslin Institute, a government-funded research institute, and PPL Therapeutics, a private for-profit firm. Economic processes interacted intimately with scientific and technological processes in the designing of Dolly.

3.5.3 Schumpeterian Economics

Schumpeter identifies two main patterns of innovative activities. The first is proposed in the "Theory of Economic Development" (***Schumpeter Mark I***), which the innovation pattern is characterized by *creative destruction*. In that framework, start-ups and new entrepreneurs play a key role in innovative activities. The innovative base is continuously enlarged by the entry of new firms. They explore new fields of technologies, which can erode the competitive advantage of established firms. The second, proposed in "Capitalism, Socialism and Democracy" (***Schumpeter Mark II***), emphasizes the importance of profit for investing in R&D in the industry. Thus large well-established firms contribute a lot to innovative activities in an economy. This innovation pattern is based on accumulation of technological and innovative capabilities, and therefore characterized by *creative accumulation*. Malerba and Orsenigo (1996) point out that the "technological imperative and technology-related factors, such as technological regimes, defined in terms of opportunity, appropriability, cumulativeness and knowledge-based features, play a major role in determining which pattern of innovative activities of a technological class prevails across countries."

The emergence of modern biotechnology since the mid-1970s can be mainly regarded as a technological breakthrough in the way drugs are discovered, developed, and manufactured relative to the traditional, chemical-based pharmaceutical framework. It has given rise to numerous new biotech firms but did not initiate a *Schumpeterian* process of *creative destruction*, which could lead to the replacement of incumbents by new entrants in other cases. Well-established pharmaceutical companies have financial and managerial resources to adapt to such radical technological changes via strategic alliances with new biotech firms, and still dominate in the drug business. New biotech firms have not replaced incumbent pharmaceutical companies, and contrarily, used extensive cooperation with them to commercialize the new technologies. For example, Genentech licensed its human insulin based on recombinant DNA to Eli Lilly instead of commercializing it on its own. There has been a symbiotic coexistence between incumbents and new entrants in the biopharmaceutical arena.

Besides, Orsenigo, Pammolli, and Riccaboni (2001) found that two different logics of exploration and technological advance have been coexisting and complementing each other in the process of biotech evolution. The first path has been following a trajectory of increasing specification of biological hypothesis. The second has been progressing towards the development of transversal techniques to generate and screen compounds and molecules. These result in the growth of specialized technology producers, new biotech firms. They also found that in the drug business, early entrants have enjoyed significant first mover advantages, while new entrants have tended to remain specialists. Large established companies, generalists, have been able to absorb increasingly specific knowledge by interacting with the universities and new biotech firms, while new biotech firms, specialists, could master at best only fragments of the technological knowledge, and found it much harder to move into the more integrated phase.

Furthermore, Lemarie, De Looze and Mangematin (2000) used the data from the Genetic Engineering catalogue to analyze 228 European biotech firms, and demonstrated that the rapid technological progress in the biotechnology cannot be derived from a rapid evolution of technology base of the established firms, and should instead be explained by the entry of a lot of new firms. It is because most of the biotech firms are so small that they are frequently associated with their original technology and cannot afford to adopt a lot of new technologies at a time. Therefore, the evolution of the technology base at the industrial level is primarily due to increasing number of new firms, not due to the growth of innovative capacity of existing biotech firms. That is, the innovative base in the biotechnology is continuously enlarged by the entry of new firms for the moment.

3.6. Policy Implications

3.6.1. Market Failures vs. Systemic Failures

Traditional S&T policies emphasize providing public goods and subsidizing R&D to correct *market failures*. The NIS framework suggests that, governments should also address *systemic failures* that block the functioning of innovation systems, hinder the knowledge flow and technology diffusion, and consequently, reduce the overall efficiency of R&D efforts. Such *systemic failures* can emerge from mismatches between different components of an innovation system, such as conflicting incentives for market and non-market institutions (e.g. firms, research institutes, universities), or from institutional rigidities based on narrow specialization, asymmetric information and communication gaps, and lack of networking and mobility of personnel. Therefore policies for innovation in the knowledge-based economy should focus on the following. (OECD, 1999)

(1) Building an innovation culture both within a firm and within an economy

(2) Enhancing knowledge exchange and technology diffusion throughout an economy

(3) Promoting clustering and networking by concentrating on the R&D infrastructure, and by strengthening academia-industry links as well as encouraging cooperation among firms

(4) Leveraging research and development by fostering commercialization of R&D through patents, licensings, and spin-off firms

(5) Responding to globalization by participating in international cooperation in R&D

3.6.2. Mission-oriented vs. Diffusion-oriented Policy

Ergas (1987) introduced the concepts of *mission-oriented* and *diffusion-oriented* policy designs to classify and analyze national innovation systems. According to him, *mission-oriented* policies are characterized by centralization and the concentration of support on a small number of technologies and representative firms, while *diffusion-oriented* policies are to build up an economy's capacity of innovating by concentrating on the R&D infrastructure, technology transfer and cooperation[7].

3.7. Concluding Remarks

For those emerging technological areas, particularly in the research-based industries, the optimization of the interface between science and economy has become one of the most important guidelines of S&T policy. Policy makers are trying to improve the effectiveness of different forms of technology transfer in order to bridge the gap between academic research, technological development activities and the commercial world.

Greater movement of scientists between university and industry promotes greater accessibility of firms to the stock of knowledge and human capital as well as greater market awareness among academics, which in turn enhances the flow of knowledge between the academia and the industry. The government, therefore, should provide an incentive to professors to blend academic and industrial research in their careers, and try to reduce their "opportunity cost" (i.e., the potential loss of academic standing) of leaving the academia for the industry. For example, the evaluation and promotion systems in universities should take scientists' contributions in addition to academic publications, say patents granted and technology licensing, into consideration. Moreover, universities should encourage full professors to engage themselves in industrial consulting and in creating start-ups or spin-offs as well as to resume their academic standing and financial status once they return back to university from the commercial world. Furthermore, academic entrepreneurs should be respected in a society as much as if they stayed in the academia, and their successful commercial experiences should be commended (or at least not be attacked by their peers).

The formation of clusters centered on publicly-funded research institutions,

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[7] Cantner and Pyka (2000) found Germany technology policy over the last 20 years had been going from specifying and defining research objectives to a more institutional and indirect funding of a diversity of actors and projects with competition, working on selecting the comparatively best solutions. For the areas of applied research and innovation, this reorientation shows up in a switch from mission-oriented to a straightforward diffusion-oriented policy focus.

including universities, is considered to be the best way to transfer technology from the academia to the industry in the knowledge-based economy. The public research institutions absorb and accumulate knowledge mainly derived from the academia arena, they generate new knowledge by conducting their own research, and then they diffuse the knowledge into the economy through publications, licensings, and academic start-ups. While some types of knowledge transmission rely primarily on the codification of information, such as reports and papers, other kinds of knowledge need personal interaction in order to be transferred. The main channels for knowledge spillovers from publicly-funded research institutions into the economy that require personal interaction are conducting joint R&D projects with the private sectors, carrying out contract research or innovation-related services such as testing and consulting, training personnel, and informal exchanges of know-how and market information. It is because such knowledge transfers involve face-to-face contacts, so the geographic proximity of publicly-funded research institutions and private firms is quite important for the process of knowledge diffusion. Therefore, spatial clustering and the resulting agglomeration economies for cooperation and competitiveness play a crucial role in the knowledge-based economy, even facing the trend of globalization.

The concept of NIS highlights the importance of flows and linkages between firms and external sources of knowledge within a country. As the global economy evolves toward knowledge-based competition, it is imperative to build up an infrastructure for facilitating revolutionary innovation through knowledge fusion, bringing together players with very different disciplinary roots, objectives, expectations, traditions, and cultures to create new knowledge within an innovation system, regionally, nationally and internationally.